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Comparison of Balloonsonde and Remote Sensing Atmospheric Measurements

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1. INTRODUCTION

The most effective deterrent to the hazardous build up of airframe ice is the avoidance of those atmospheric regions where meteorological conditions make its accretion possible. This avoidance is only possible through forewarning the pilot, which today is accomplished through the use of pilot encounter reports or weather analysis. A better method is the measurement of actual atmospheric conditions, which requires either the widespread deployment of in-situ measurement devices or the development of remote sensing instrumentation. As part of its aircraft icing research program, the NASA Glenn Research Center is conducting a program to develop technologies for the remote sensing of atmospheric conditions that are conducive to icing (Reehorst, 2003). The goal of the program is to develop an integrated package of instruments, suitable for incorporation into the aircraft, which would provide the flight crew with sufficient warning to avoid a region of potential danger (Reehorst, 2001). A suite of instruments, currently ground based, is used to identify a region of supercooled liquid water which is labeled as hazardous if its water content is sufficiently high.

During the recently completed Alliance Icing Research Study (AIRS II), these instruments were deployed in conjunction with those of other U.S. and Canadian researchers at the Mirabel Airport near Montreal, Quebec. As part of the study, balloonsondes were employed to provide in-situ measurement of the atmospheric conditions that were being concurrently remotely sensed. Balloonsonde launches occurred daily at 1200 UTC to provide AIRS forecasters with local data, and, additionally when research aircraft were present in the airspace. Data from the soundings are compared with the processed data from the NASA remote sensing instruments, which include an X-band radar, a ceilometer and radiometers.

2. EXPERIMENTAL INSTRUMENTATION

2.1 Balloonsonde System

The balloonsonde system used in the AIRS II study is a commercially available product from the VIZ Meteorological Systems Group of Sippican, Inc. The Model W-9000 Meteorological Processing System is an integrated hardware and software package that provides meteorological profiles through the use of telemetered radiosonde data and Global Positioning Satellite (GPS) location data.

The balloon-borne radiosonde sensors, transmitters and GPS receiver are contained in a molded foam case, approximately 500 grams in weight, including a water-activated battery that is typically good for two hours of flight. Temperature and humidity are directly measured, while pressure is calculated from GPS data and the Standard Atmosphere. Temperature is obtained using a standard rod thermistor fabricated from mined iron oxide, positioned at the end of an arm to remove it from the close proximity of the sonde case. Heating from solar radiation, as well as the wet bulb effect from water retention, is minimized by the application of reflective, then surfactant, coatings on the sensor. The range of measurement is +50 ˚C to –100 ˚C with an accuracy of 0.2 ˚C A deposited carbon film on an acrylic substrate is used for humidity measurement. This configuration is been well known for superior performance at higher humidity levels (>20%). Recent development has improved the performance of the sensor at lower humidity levels; after calibration at both 33% RH and 11%

RH a linear interpolation is used for this range. The sensor is installed in a tube integral to the foam sonde case. This location prevents direct solar radiation from warming the element and rain from impinging on the carbon film. Response time is typically less than one second.

Direct measurement of the ambient pressure is not employed in the sondes used in this study. The sondes are instead equipped with a GPS receiver, which acquires the signal from 5-7 satellites prior to launch. The base station also uses GPS to determine its location. The resulting comparison of positional data is used to calculate sonde altitude, latitude and longitude, its velocity with respect to the launch site and rate of ascent. An additional spare data channel was available on the sonde, which was not utilized.

The meteorological data, calibration values and GPS parameters are sampled and transmitted to the ground station once per second, with the data set retransmitted a second time for reliability. The transmitter operates at 403 MHz, tunable over a range of 400 to 406 MHz. The sonde transmitter has a nominal radiated power of 250 milliwatts, sufficient to allow for data collection over a range of 200 km when using the directional, six element Yagi antennas. The ground station includes the 403 MHz receiver and antenna controller, a GPS receiver and an serial interface for initializing the radiosonde. System control and data display and storage is accomplished through the use of laptop computer. Data can be viewed during the flight in either a graphical or tabular mode. WMO coding is available for processing the data into coded messages for transmission, with all flight data stored on the hard drive of the computer. The ground station and a balloon sonde ready for launch is seen in Figure 1. Figure 2 shows a launch of the balloon sonde. The multi-element direction antenna is visible on the roof of the building.

Figure 1, Balloonsonde system ready for launch, ground station and data acquisition system is on table at left.

2.2 Remote Sensing System

Four instruments currently comprise the NASA icing remote sensing system: two radiometers, one that measures multiple frequencies between 22 and 59 GHz and another that measures at 89 and 150 GHz; a vertically staring X-band radar and a lidar ceilometer. Instrument control and data acquisition for all instruments is through individual personal computers.

Two Radiometrics Corporation microwave radiometers were deployed at Mirabel Airport. The TP/WVP-3000 profiling radiometer provides temperature and water vapor profiles from the surface to 10 km, and low-resolution liquid water profiles. Observations using seven frequencies

Figure 2, Launch of balloonsonde at Mirabel Airport, multi-element direction antenna is visible on the building roof.

from 52 to 59 GHz are used to determine temperature measurement as a function of altitude. Cloud water vapor content is determined through the observation of five frequencies in the 22 to 30 GHz range. Information on the liquid water content of the cloud is obtained by measurement of microwave energy as a function of frequency near 22 GHz and by scanning on either side of 60 GHz. The second radiometer, operates at 89 and 150 GHz with elevation scanning capability and dual polarization at 89 GHz. Its purpose is to discriminate ice from liquid water in meteorological conditions that may be associated with aircraft icing. Both radiometers are free standing, as is the ceilometer.

The X-band radar is a Honeywell WU-870 airborne weather radar unit which utilizes a 24-in diameter, flat-plate antenna operating at 9375 MHz. The radar is configured in a vertical staring mode. It has been modified to allow the use of a PC running under the Windows XP operating system for data acquisition instead of the standard Honeywell flight control/display unit. The radar transmitter/receiver antenna is mounted in the roof of the trailer, protected from the weather by a radome.

Figure 3, Remote sensing system deployed at Mirabel Airport. The radar dome is seen on the roof of the trailer in the foreground, with the ceilometer on the ground directly behind it. The two radiometers are at the center rear of the photograph.

Cloud base and height as well as vertical visibility are measured using a lidar ceilometer. The instrument, a Vaisala Model CT25K, employs a pulsed diode laser operating in the infrared wavelengths (905 nm) and is able to detect up to three cloud layers simultaneously. The data acquisition systems for all of the remote sensing instruments are located in a trailer which is also used for equipment transportation. The trailer and instruments, Figure 3, were situated about 1 km from the balloonsonde launch site.

3. RESULTS AND DISCUSSION

Although the AIRS II field test program ran from November, 2003 through February, 2004, the NASA remote sensing system was operational on-site only during the 2003 portion of the study. During this period, 70 of the 89 balloonsonde launches took place, with nine of these coincident with the optimum datasets from the remote sensing system. Optimum conditions in this case encompass rain free conditions and dry radiometer windows. In this paper the results of two representative flights are examined. Temperature and relative humidity as a function of altitude through 10 km from the TP/WVP 3000 radiometer and balloonsonde are compared.

Comparisons of this data for a November 11, 2003, 15:35 UTC launch are shown in Figures 4.1 (temperature) and 4.2 (relative humidity). Sonde initial ascension rates were about 5 m/s, so the data covering the first 10 km of altitude were collected over a 30-35 min period of time. The radiometer data were taken from a single scan during the middle of the sonde ascent through 10 km. The temperature profile of the radiometer agreed well with the balloonsonde data. The average difference in values over the data set is 1.7 ˚C with the greatest difference 4.45 ˚C at about 2 km altitude. Above 6 km, the radiometer read consistently colder by about 2.5 ˚C, which agrees well with earlier results (Reehorst, 2001A). A probable cause is the training of the artificial neural network used in retrieving water vapor, cloud liquid water and temperature profiles from the radiometric data. Although it was trained using

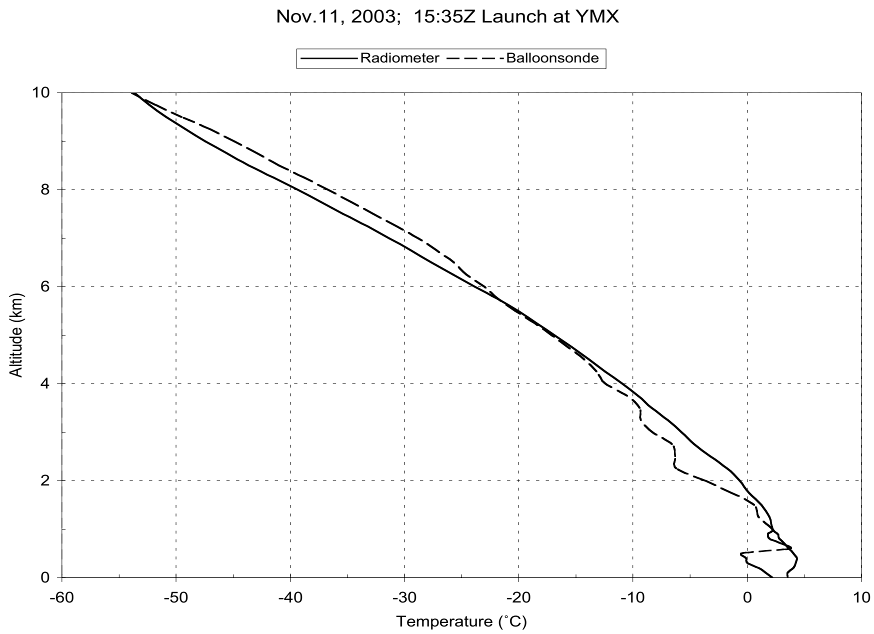

Figure 4.1, Temperature comparison for November 11, 2003, 15:35 UTC launch.

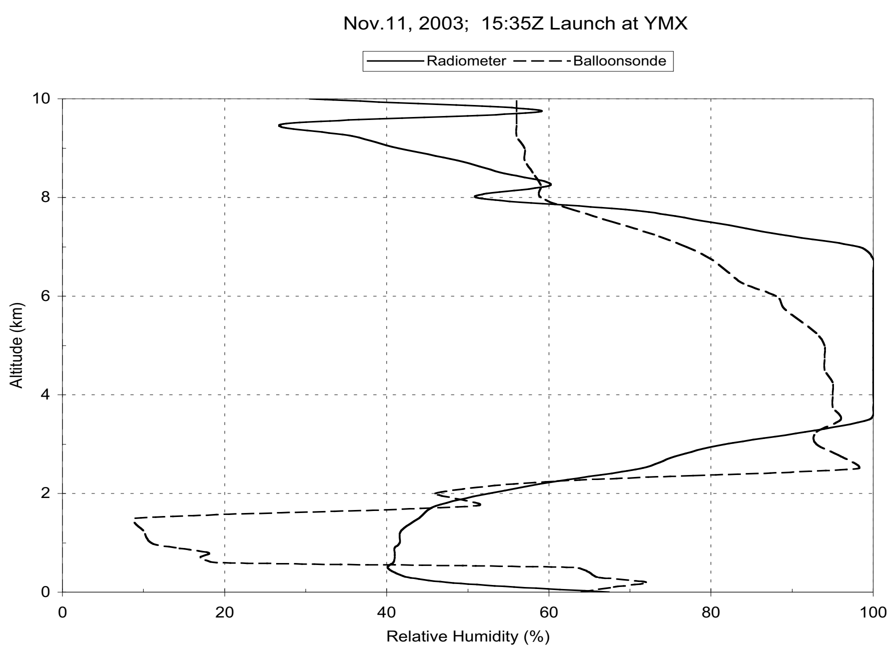

Figure 4.2, Relative humidity comparison for November 11, 2003, 15:35 UTC launch.

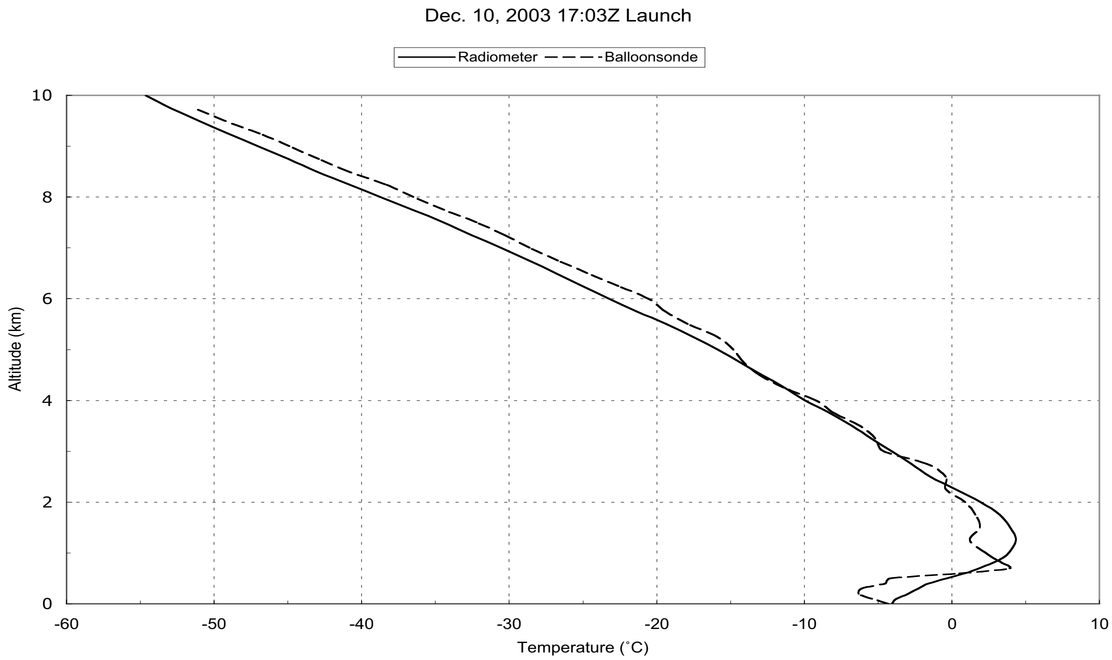

Figure 5.1, Temperature comparison for December 10, 2003, 17:03 UTC launch.

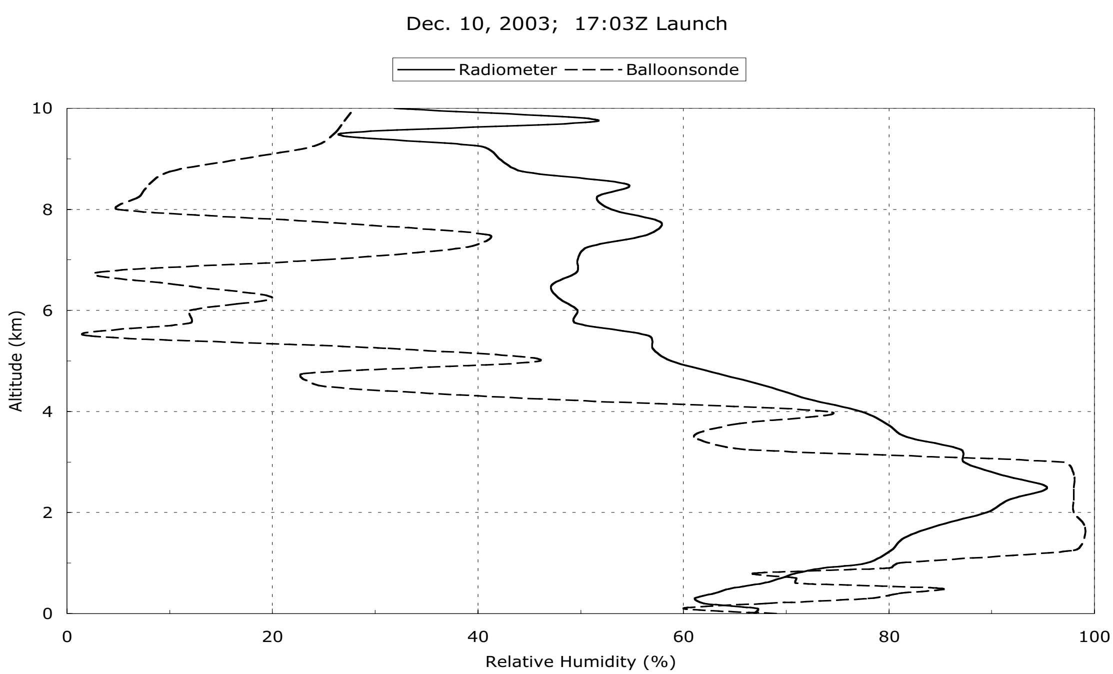

Figure 5.2, Relative humidity comparison for December 10, 2003 17:03 UTC launch.

data from the Montreal area, accuracy is directly dependent upon the close match of the training data with those conditions encountered during the field study. Other possible sources of error are the gradual decay of radiometer accuracy with increasing altitude and the continuous drift of the sonde during flight; horizontal wind speed reached 40 m/s above 6 km. Similar results are seen in Figure 5.1, the temperature profiles from a December 10, 2003, 17:03 UTC launch. In this case the average temperature difference was 1.6 ˚C with a maximum difference of 3.85 ˚C at 0.5 km. Above 5 km, the difference was about 2 ˚C, similar to the previous case. Winds were lighter in this case, reaching 14 m/s near 10 km.

With regard to relative humidity, larger discrepancies are seen between the radiometer and balloonsonde data than were seen in the temperature comparison. Figures 4.2 and 5.2 show relative humidity as a function of altitude for the two launches. For the November 11 data, there was a dry zone from just above ground level to 1.75 km. The radiometer is not particularly good in tracking this rapid decrease in humidity nor does it accurately track the lowest humidity portions of the band. Ceilometer data for this time period shows a cloud deck with a lower boundary at 2.1 km, which agrees well with both the radiometer and sonde data. The radiometer generally tracks well with the sonde up to 8 km. Above 8 km, the radiometer data deviates again from the sonde, as in the temperature cases, possible causes are the training of the radiometer neural-net, drift of the sonde from its launch position and increasing inaccuracy of the radiometer with altitude.

For the December 10 case, ceilometry shows a layer of clouds with a base at about 1.2 km. Both the radiometer and sonde track this well, although the radiometer deviates significantly at the upper and lower boundaries of the cloud, which are areas of rapid change of humidity. Above this layer, the air becomes quite dry, with dew points in the –60 ˚C range. The radiometer consistently mis-measures the humidity under these increasingly dry conditions.

4. CONCLUSION

Comparison of remotely sensed (radiometer) temperature and relative humidity with in situ measurements (balloonsonde) during the AIRS II field program reveals strengths and shortcomings. The ability of the radiometer to accurately track temperature was good, particularly at lower altitudes. The discrepancy from sonde data above 5 km was generally constant and could be due to mismatch between the dataset used to train the radiometer neural-net and actual conditions, drift of the sonde with time or decreasing inaccuracy of the radiometer with altitude. Agreement with regard to relative humidity was not as good. The radiometer is not able to track rapid changes in humidity and appears to return consistently high humidity values in area of very dry air. In all cases, both systems accurately measured the boundaries of cloud layers as delineated by the ceilometer. Despite these deficiencies, the results from the AIRS II field test demonstrated the soundness of the basic concepts of the remote sensing system.

Future work includes the automation of methods of comparison of the large volumes of data generated by these systems, which at present are not easily compared. The radiosonde system will be installed in the aircraft hangar at NASA Glenn in Cleveland for the upcoming icing flight season, in close proximity to the remote sensing system. This will allow for simultaneous remote and in situ (both the balloonsonde system and the icing research aircraft) sensing of the conditions of interest. The development of a liquid water content sensor for integration into the radiosonde is also of interest and is under study.

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13. ABSTRACT ***(Maximum 200 words)***

As part of its aircraft icing research program, the NASA Glenn Research Center is conducting a program to develop technologies for the remote sensing of atmospheric conditions. A suite of instruments, currently ground-based, are used to identify a region of supercooled liquid water which is labeled as hazardous if its liquid water content is sufficiently high. During the recently completed Alliance Icing Research Study (AIRS II), these instruments were deployed in conjunction with those of other U.S. and Canadian researchers at the Mirabel Airport near Montreal. As part of the study, balloonsondes were employed to provide in-situ measurement of the atmospheric conditions that were being concurrently remotely sensed. Balloonsonde launches occurred daily at 1200 GMT to provide AIRS forecasters with local data and additionally when research aircraft were present in the airspace. In this paper, we compare the processed data from the NASA remote sensing instruments, which included an X-band radar, lidar and two radiometers, to the data gathered from the 70 soundings conducted while the NASA instruments were active. Among the parameters compared are cloud upper and lower boundaries, temperature and humidity profiles and freezing levels.

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